(54) Title: SUBSTRATE TEMPERATURE MEASUREMENT BY INFRARED SPECTROSCOPY

(57) Abstract

The temperature of an infrared radiation scattering medium which contains water, for example, biological tissue and paper, cement and clay substrates, is determined by exposing the medium to infrared radiation, measuring the reflected radiation scattered by the medium, comparing the reflected radiation with calibrated values, and evaluating the temperature of the medium from the comparison; the technique provides a means of non-invasive determination of temperature in biological tissue which has utility in medical diagnosis.

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SUBSTRATE TEMPERATURE MEASUREMENT BY
INFRARED SPECTROSCOPY

TECHNICAL FIELD

5   This invention relates to determination of a
parameter of a medium which scatters infrared
radiation; in particular, it is concerned with a
method and apparatus for determining the temperature
of such a medium.

10   The invention has particular application to the
determination of the temperature of biological tissue,
but also has application to other media which contain
water and which scatter infrared radiation, for
example, substrates in paper, cement and clay product
15   manufacture.

          The invention is more especially concerned with
a method and apparatus for quantitative, non-invasive
bioenergetic measurement. Towards this end, a method
and apparatus for determining tissue temperature is
20   provided.

BACKGROUND ART

          Tissue   temperature   is   critical   to   cellular
bioenergetics and can be useful clinically to locate
blood perfused regions in diseased or inflamed tissue.
25   Clinical use of tissue temperature or thermography has
been   limited   by   uncertainties   in   temperature
measurement. The most common method for temperature
measurement is to use invasive micro-electrodes or
thermocouples.   However, these probes have several
30   disadvantages, including: tissue damage, alterations
of tissue temperature and single point detection.
Measurement of tissue temperature using emitted light
in the infrared or microwave region has overcome many
of   the   disadvantages   of   electrode   measurements.
35   Assuming   the   tissue   is   a   blackbody   radiator,   non-

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invasive images of tissue are possible using infrared emission. However, the extremely high extinction coefficients for the infrared wavelengths in wet tissue result in light penetration of a few hundred
5   microns or less. For wet tissue such as the lung or gut, this penetration depth is not sufficient. Likewise, infrared light is not easily coupled into fiber optic systems for endoscopic or bronchoscopic measurements.

10   **DISCLOSURE OF THE INVENTION**

The present invention employs measurements of the reflectance infrared spectra from a specimen, especially the near-infrared spectra. Temperature dependent changes in the hydrogen bonding of water
15   within the specimen, for example tissue, results in change of the reflectance spectra. Using sets of specimen measurements with known temperature, a calibration equation is determined by statistical analysis of the data. Computer simulations and
20   infrared, especially near-infrared, measurements of known phantoms are used to evaluate the sensitivity of the method for studies of specimens with different scattering properties. The system provides a new tool to study local specimen temperature thereby providing
25   a means for rapid, non-invasive measurement of parameters, for example, parameters critical to bioenergetics in tissue for research and clinical use.

Thus in accordance with the invention there is provided a method of determining the temperature of an
30   infrared radiation scattering medium comprising: exposing an infrared scattering medium containing a liquid which contains different hydrogen bonding at different temperatures to infrared radiation, measuring reflected infrared radiation scattered by
35   the medium, comparing the reflected radiation with

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calibrated values of reflected radiation and temperature, and evaluating the temperature of the medium from the comparison.

5   In particular the radiation has a near-infrared wavelength between 700 nm and 2500 nm.

In particular reflected infrared radiation at different wavelengths is measured. In particular, the different wavelengths comprise wavelengths for water between 1100 and 1300 nm including a wavelength for

10   free OH groups and a wavelength for hydrogen-bonded OH groups.

In another aspect of the invention there is provided an apparatus for determining the temperature, of an infrared radiation scattering medium comprising:

15   i) a plurality of optical fibers effective to transmit infrared radiation from a source to a scattering medium and to transmit reflected, scattered radiation from said scattering medium, ii) a source of infrared radiation operatively associated with said fibers for

20   transmission of infrared radiation, iii) detector means adapted to receive reflected radiation for multiple wavelengths from said optical fibers and issue signals responsive thereto, and iv) evaluating means for receiving said signals and determining the

25   temperature of the scattering medium therefrom.

Although the invention is not restricted to the use of near-infrared radiation, such radiation is preferred for non-invasive temperature measurements of biological tissue because absorption of light is low

30   in this spectral region and non-invasive measurements can be made through intervening tissue. Furthermore, commercially available endoscopes transmit near-infrared radiation, but are not adapted to transmit mid or far-infrared radiation. Mid and far-infrared

35   radiation are acceptable for other applications,

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particularly those involving surface measurements of temperature.

In particular, the optical fibers are associated with an endoscope, for example, a
5 bronchoscope, a cystoscope or a gastroscope, effective for entry to the respiratory, urinary and gastro-intestinal tracts respectively, whereby minimally invasive examination can be conducted, including visual observation and temperature determination of
10 different specific sites of biological tissue, for example, lung tissue, in accordance with the invention.

Typically the endoscope will include an eyepiece for viewing the tissue or may include a
15 camera linked to a television on which an image of the tissue can be viewed. In this way it is possible to view the tissue at different sites and, by means of the invention, determine the temperatures of such sites. Thus, for example, degree of inflammation may
20 be assessed, not only by visual examination, but also, more precisely, by temperature determination.

The detector suitably comprises an infrared spectro photometer, preferably a multiwavelength near-infrared Fourier transform or dispersive spectro
25 photometer or a spectrophotometer having filters adapted to separate the multiple wavelengths, the filters suitably being for hydrogen bonding wavelengths in the range of 900 to 1300, suitably 1100 to 1300 nm, more especially a first filter for a
30 wavelength for free OH groups and a second filter for a wavelength for hydrogen-bonded OH groups.

Suitably the detector includes a diode array detector, or similar device, for issuing signals, particularly electrical pulses, based on the received
35 or separated wavelengths. These signals are fed to a

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computer or equivalent device which permits comparison of the signals with an established relationship between wavelength and temperature for the tissue, whereby the temperature of a specific site can be

5   evaluated.   The procedure is repeated at different sites.

In particular embodiments the medium is a biological tissue, a paper substrate, cement or a clay substrate, but the invention may also be employed in

10 conjunction with other water-containing media which scatter infrared radiation.

The invention has particular application in non-invasive medical diagnosis.

DESCRIPTION OF PREFERRED EMBODIMENTS

15   The calibration values may be determined for specimens at known temperature, and the development of such calibration values is well within the skill of persons in the art.   The comparison values may be stored in comparison tables, or more conveniently in

20 software which readily provide an evaluation of the temperature based on the measured scattered radiation and the comparison values.

The near-infrared wavelength region between 700 nm and 2500 nm has significant penetration into tissue

25 and can be readily incorporated into fiber optic systems.   The relatively short wavelength (high energy) of the near infrared as compared to the mid-infrared and microwave spectral region, show little blackbody emission and are unsuited for classic

30 thermographic measurements.

Typically, in tissue the diffuse reflectance spectrum is dominated by the absorbance bands associated with the OH groups in water.   There are many OH absorbances in the near-infrared region.   Due

35 to differences in hydrogen bonding, the spectrum of

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water will change at different temperatures. The near infrared spectral differences can be used to make an accurate temperature sensor of a pure non-scattering water sample with measurements within 0.1°C being
5   possible.

A temperature calibration using pure water will, however, not accurately measure temperature in tissue. This is due to the presence of additional absorbers in tissue along with tissue scattering. The
10 present invention provides a means to calibrate temperature in tissue using water absorbance thereby providing a robust measure of temperature regardless of specimen composition or scattering properties. The invention is also applicable to media containing
15 liquids other than water which contain different hydrogen bonding at different temperatures.

Information retrieval from broad, overlapping spectra is not trivial due to effects of interfering bands. Fundamental to successful statistical analysis
20 is a valid training data set of spectra with quality factors that have been determined by independent reference methods. Equations relating the quality factors to the spectra of the training set are obtained by statistical regression techniques. The
25 resulting transformation rules obtained by statistical regression analysis are subjected to validation using independently measured sets of samples. With successful verification, the transformation rule can then be used to derive predicted values of sample
30 properties. Multivariate approaches overcome the problem of overlapping absorbances and allow simultaneous multiproperty analysis.

There are two general approaches to the statistical regression analysis - 1) methods that
35 utilize full spectra for transformation such as

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partial least squares (H. Martens and S. A. Jensen, Partial Least Squares Regression: A New Two-Stage NIR Calibration Method. In Progress in Cereal Chemistry and Technology, Vol. 5a (J. Holas and J. Kratochvil,
5   eds.), Elsevier, Amsterdam, 607:647, (1983)), PLS, or 2) methods that select individual wavelengths with the highest correlation coefficients for the quality factors, such as stepwise linear regression (I. Ben-Gera and K. H. Norris, J. Food Sci., 33:64 (1968)),
10   SMLR. The SMLR methods are most appropriate for transformation of predictive equations to filter-based instrument designs, but PLS results give a somewhat better estimate of the overall information content of spectra.

15   In one embodiment of this invention analytical predictive equations are employed different from the approaches of prior methods. Prior methods perform various math treatments of spectra such as smoothing and/or derivative calculations prior to SMLR analysis.
20   Analyses are carried out on these sets of smoothed and differentiated spectra. Combinations of wavelengths are sought which produce the highest regression coefficients with lowest standard errors of regression. Selected combinations of wavelengths are
25   then used to predict values of test sets and final conditions are selected based upon standard errors of prediction. The result is that all wavelengths in the spectra have had the same math treatment. Thus SMLR methods produce prediction equations with filters all
30   having the same bandwidths.

The method in the new embodiment is similar to the SMLR method, the result, particularly for the design of filter-based instrumentation, is quite different. The spectra are not preprocessed by
35   smoothing, instead the untreated training sets are

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used to calculate optimal filters with varying center wavelengths and bandwidths. In this approach each predicted filter has an associated bandwidth which produces the most robust prediction. Thus the
5   proposed method produces filter specifications optimized for the conditions of a filter spectrometer instead of filter specifications based on optimizing the original data acquisition and treatment procedures.

10 **BRIEF DESCRIPTION OF DRAWINGS**

FIG. 1 illustrates schematically an apparatus in accordance with one embodiment of the invention;

FIG. 2 illustrates schematically an apparatus in accordance with another embodiment of the
15 invention;

FIG. 3 shows near-infrared spectra for water at 25°C and 50°C;

FIG. 4 is a linear plot developed from an SMLR algorithm from the data of FIG. 3;

20 FIG. 5 shows a lung tissue spectra derived in accordance with the invention;

FIG. 6 is a linear plot derived from the data in FIG. 5;

FIG. 7 is a muscle tissue spectra derived in
25 accordance with the invention;

FIG. 8 is a linear plot derived from the data in FIG. 7;

FIG. 9 is a plot of change in spectra with increase in temperature for a cooled human finger in
30 vivo;

FIG. 10 is a second derivation spectral plot derived from FIG. 9;

FIG. 11 is a calibration derived from the data of FIGS. 9 and 10; and

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FIG. 12 is a similar calibration for a second
set of test data.

MODES OF CARRYING OUT THE INVENTION

With further reference to FIG. 1, apparatus 10
5   includes a bronchoscope 12 associated with a plurality
of optical fibers 14, a detector 16, a computer 18 and
a source 20 of radiation, for example, an intensity
stabilized tungsten-halogen light.

Detector 16 includes a spectrophotometer 22 and
10   a charge coupled detector array 24.

Spectrophotometer 22 includes a beam splitter
26 and filters 28 and 30 for different wavelengths.
Mirrors 32, 34 and 26 reflect the beams of different
wavelength from filters 28 and 30 to the array 24.

15   The detector 16 further includes a camera 38.

The fibers 14 are contained within a tubular
housing 40 having a head 42 which may be cooled by a
chiller 44.

In operation radiation, preferably near-
20   infrared radiation is transmitted from source 20 to
the bronchoscope 12 and passes along the optical
fibers 14 from which it is delivered to a lung tissue
site being investigated by the bronchoscope

The fibers 14 may include separate fibers for
25   delivery of transmitted radiation and return of
reflected radiation, or the same fibers may serve both
functions.

The radiation is reflected by the tissue at a
site under investigation and is transmitted to
30   spectrophotometer 22 where it is split by beam
splitter 26 into two components. One component passes
through filter 28 which isolates a wavelength
associated with free OH groups of water in the tissue
and the second component passes through filter 30

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which isolates a wavelength associated with hydrogen-bonded OH groups of water in the tissue.

The wavelength passing filter 28 is reflected by mirror 32 and the reflected beam travels to array
5   24. The wavelength passing filter 30 is reflected by mirrors 34 and 36 and the reflected beam similarly travels to array 24.

The array 24 issues signals responsive to each of the reflected beams and these signals are recorded
10   in computer 18 to generate an image. Computer 18 compares the signals with a previously established relationship between temperature and wavelength and provides a temperature result or image for each signal derived from such relationship.

15   This procedure is repeated for different sites of the lung tissue.

The reflected beams may also be fed through a camera 38 from which an image of the site under investigation can be developed.

20   As an alternative to measuring temperature, the rate of tissue rewarming can be evaluated; for this purpose a chiller 44 associated with the head 42 of the housing 40 of the fibers 14, cools the tissue at a site under investigation and the shift in wavelength
25   as the temperature rises after the chilling effect is interrupted, is monitored.

The array 24 may, for example, be a photo diode array which produces an electrical pulse responsive to radiation received, from which electrical pulses on
30   image can be obtained.

With further reference to FIG. 2, apparatus 100 is similar to apparatus 10 of FIG. 1, and in so far as it employs the same components, the same identification integers are employed as in FIG. 1.

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Thus apparatus 100 includes bronchoscope 12, optical fibers 14, computer 18 and source 20 as well as chiller 44.

A detector 116 includes a spectrophotometer 122
5   and a photodiode array 124.

Within spectrophotometer 122 is housed an entrance slit 150 and a concave diffraction grating 152.

In use radiation is reflected by the tissue at
10 a site under investigation and is transmitted to spectrophotometer 122 where it passes through entrance slit 150. The reflected radiation is diffracted into a range of wavelengths from low wavelength to high wavelength, in grating 152 and the thus diffracted or
15 dispersed wavelengths are received by photodiode array 124 which issues a signal, more especially an electrical signal, responsive to individual wavelengths, which signals are fed to computer 18 as in FIG. 1.

20 **EXAMPLES**

EXAMPLE 1

i) INSTRUMENTATION/SOFTWARE

Spectral data was collected using a modified Nicolet 550 Fourier transform spectrometer. The
25 system was controlled with a personal computer (AMT, 486-66MHz). To provide sufficient signal-to-noise for temperature estimation, the signal from 128 scans was integrated in all of the measurements presented here. A custom temperature controlled sample holder was made
30 to allow both transmission and scattering measurements. Reference temperature for the samples was measured using a Fluke M50 thermocouple detector. The detector is sensitive to 0.1°C.

The OMNIC data analysis package (Nicolet), was
35 used to determine the calibration coefficients for

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thermal measurements. The major component used in the OMNIC package was the Partial Least Squares (PLS) regression routine.

ii) RESULTS

5   Dependence of the near-infrared absorbance of water on temperature was determined by heating a 4 mm thick cuvette of pure water to 50°C and measuring spectra along with associated temperatures as the sample cooled to room temperature. Examples of the
10   measured near-infrared spectra are shown in FIG. 3. A substantial change in spectral absorbance of water is observed with changes of temperature. A PLS regression was made using the data in FIG. 3 to determine the calibration coefficients. Four
15   independent factors were chosen in the PLS calibration. Results are plotted and a linear calibration is seen with an error of 0.1°C. FIG. 4 is typical of the linear plot derived in this manner.

      To confirm that temperature calibration
20   measurements in pure water could accurately predict temperature in tissue, a series of spectral measurements were made at a 4 mm thick piece of lung tissue (bronchus) at different temperatures within the calibration region. The lung tissue spectra are shown
25   in FIG. 5. The tissue spectra are similar to the pure water spectra, however, there is a significant baseline component present in the tissue spectra. Temperature of the lung tissue was predicted using the calibration coefficients from the pure water sample.
30   There is significant error in the temperature measurements with some non-linearity. This is a result of the difference in the scatterers and other absorbers in the tissue spectra as compared to the pure water measurements. This would not be very
35   useful for clinical measurements of tissue

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temperature, since, at best, a two point calibration would be required to adjust the estimated temperature for each tissue.

However, the water within the lung tissue still
5   changes with temperature and can be used to generated a temperature calibration. The PLS regression using the lung data in FIG. 5 was made to determine the temperature calibration coefficients. Three independent factors were chosen in the PLS
10 calibration. Results are plotted in FIG. 6. A linear calibration is seen with an error of 0.1°C. These results are consistent with the non-scattering water measurements. Therefore, by correcting the variations with scattering, a robust temperature calibration is
15 obtained.

To demonstrate that calibration using a single tissue type was adequate for robust temperature measurements of different tissue types, a second tissue scattering sample was used. A 3 mm thick piece
20 of excised muscle was used as the second tissue scatterer and a series of temperature correlated near-infrared spectra were taken. The measured spectra are shown in FIG. 7. Even though the muscle has significant chromogenic components in the visible
25 spectra as compared to lung tissue, the near-infrared spectral profile is very similar. However, the different scattering characteristics of the two types of tissue result in subtle differences which influence the temperature estimation.
30 One approach to the temperature calibration in variable scattering media is to construct a calibration data set which is comprised of spectral measurements made from a variety of different tissue types. As an example, when the spectral measurements
35 were combined from both the lung and muscle into one

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calibration, a significant improvement in temperature measurements was possible. The calibration results are shown in FIG. 8. As is apparent, the temperature measurements are now fairly accurate. The mean error
5 for the measurements is 1.1°C. With additional tissue types included, better calibration will be obtained.

EXAMPLE 2

An apparatus of the type illustrated in FIG. 1 but replacing the bronchoscope with an optical fiber
10 bundle was employed to measure tissue temperature in the human finger.

The system consists of an intensity stabilized tungsten-halogen light source illuminating the tissue through a fiber optic bundle. The diffuse reflected
15 light from the tissue is collected by a second fiber optic bundle which is connected to the entrance of the near infrared spectrograph. The various wavelengths are dispersed in the spectrophotometer and collected by a diode array detector. The signal from each
20 element of the detector represents the intensity of the light at a given near-infrared wavelength between 700 and 1100 nm. Digitization of the diode array is accomplished using an Insight 486-PC computer equipped with a National Instruments 16-bit, 100khz A/D-D/A
25 board. Controlling software for the system was written for signal intensity optimization and data acquisition in the tissue studies. Statistical analysis of the spectral data was accomplished using custom software written in the Matlab programming
30 language. The entire multispectral analysis system is enclosed in a shock protected housing. This has allowed convenient transport of the system to the clinic.

Since tissue is composed of mostly water and
35 proteins, an investigation was made to determine the

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relationship between the signal from water OH absorbances at different temperatures to provide a measure of the global tissue temperature. The spectral changes in the human finger were studied in vivo at
5   different temperatures. To cool the finger from ambient body temperature (37°C) the subject's hand was placed into a beaker of ice water. A calibrated thermocouple was taped on the subject's middle finger. When the finger reached approximately 10°C the subject
10   withdrew their hand and placed the fiber optic source and detector bundle next to the temperature sensor. The near infrared spectra were recorded on the finger as the tissue rewarmed using the fiber optic arrangement. During each spectral measurement the
15   temperature in the tissue was recorded using the thermocouple. The changes in the spectra with increased temperature are shown in FIG. 9. The major changes in the spectra are an increased relative magnitude with a relative change in the OH absorbances
20   at 810 nm and 960 nm. The change in magnitude of the signal is probably due to an increase in the amount of water as the tissue fills with blood and rewarming. The relative changes in the OH absorbances are due to the temperature change in the hydrogen bonding of
25   water and are similar to previous in vitro measurements. To reduce the effects of the magnitude changes on the calibration and to emphasize the difference in the OH absorbance, the second derivative of the spectral were taken. The results are shown in
30   FIG. 10. The temperature differences in the tissue spectra are clearly visible in the spectral series. Using partial least squares analysis of the spectra, calibration coefficients for the wavelengths were determined using two independent factors. Using the
35   two factors, the temperatures of the calibration set

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were estimated and are shown in FIG. 11. The accuracy
of the estimation is ± 0.7°C. To test the system on an
independent set of optical measurements, the
temperature was estimated for a second "test", set of
5   spectra from the finger. Results of the test
estimation are shown in FIG. 12. The accuracy of the
test set estimation is ± 1.0°C. As is evident, a tight
correlation between the non-invasive estimates and the
measured temperature was found in both measurements.
10   These results clearly demonstrate the feasibility of
fiber optic measurement of tissue temperature by near-
infrared spectroscopy.

      Near-infrared measurement of water provides
non-invasive temperature measurement of wet tissues.
15   For each tissue type, the temperature calibration can
be made to within the accuracy of the reference
temperature measurement system. The results suggest
that tissue compositional changes will influence
temperature estimation. To increase the robustness of
20   the calibration for different tissue types, a
calibration model can be constructed using scattering
measurements from a variety of tissues. The
availability of a non-invasive system for tissue
thermography would be applicable to a wide variety of
25   physiological questions and provide information which
improves the capability to determine disease and
inflammation in tissue. Likewise, the accurate
knowledge of tissue temperature would be helpful as a
reference for other non-invasive tissue chemical
30   measurements made in the near infrared and could be a
powerful tool for non-invasive metabolic assessment.

      The method may also be applied to techniques
which involve measurement of other factors such as
glucose concentration in which a knowledge of the
35   temperature is needed.

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Such measurements also have utility in the evaluation of other water-containing infrared radiation scattering media.

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WE CLAIM

1.　　A method of determining the temperature of an infrared radiation scattering medium comprising:

　　　a) exposing an infrared scattering medium containing a liquid which contains different hydrogen bonding at different temperatures to infrared radiation,

　　　b) measuring reflected infrared radiation scattered by the medium,

　　　c) comparing the reflected radiation with calibrated values of reflected radiation and temperature, and

　　　d) evaluating the temperature of the medium from the comparison.

2.　　A method according to claim 1, wherein said liquid is water.

3.　　A method according to claim 1 or 2, wherein said radiation has a near-infrared wavelength between 700 nm and 2500 nm.

4.　　A method according to claim 1, 2 or 3, wherein said medium is biological tissue.

5.　　A method according to claim 1, 2 or 3, wherein said medium is a paper substrate.

6.　　A method according to claim 1, 2 or 3, wherein said medium is cement.

7.　　A method according to claim 1, 2 or 3, wherein said medium is a clay substrate.

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8.   A method according to claim 1, 2, 3, 4, 5, 6 or
7, wherein step b) comprises measuring reflected
infrared radiation at different wavelengths.

5   9.   A method according to claim 8, wherein the
different wavelengths comprise wavelengths for water
between 900 and 1300 nm comprising a wavelength for
free OH groups and a wavelength for hydrogen-bonded OH
groups.
10

10.   An apparatus for determining the temperature of
an infrared radiation scattering medium comprising:
         i)   a plurality of optical fibers effective
to transmit infrared radiation from a source to a
15   scattering medium and to transmit reflected scattered
radiation from said scattering medium,
         ii)   a   source   of   infrared   radiation
operatively   associated   with   said   fibers   for
transmission of infrared radiation,
20   iii)   detector   means   adapted   to   receive
reflected radiation for multiple wavelengths from said
optical fibers and issue signals responsive thereto,
and
         iv)   evaluating   means   for   receiving   said
25   signals   and   determining   the   temperature   of   the
scattering medium therefrom

11.   An apparatus according to claim 10, including
an endoscope, said plurality of optical fibers being
30   associated with said endoscope.

12.   An apparatus according to claim 11, wherein
said detector comprises filters for said multiple
wavelengths, said filters being for hydrogen bonding
35   wavelengths in the range of 900 to 1300 nm.

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13.   An apparatus according to claim 12, wherein said filters comprise a first filter for a wavelength for free OH groups and a second filter for a
5   wavelength for hydrogen-bonded OH groups.

14.   An apparatus according to claim 11, wherein said detector means comprises a near-infrared spectrophotometer including filters adapted to
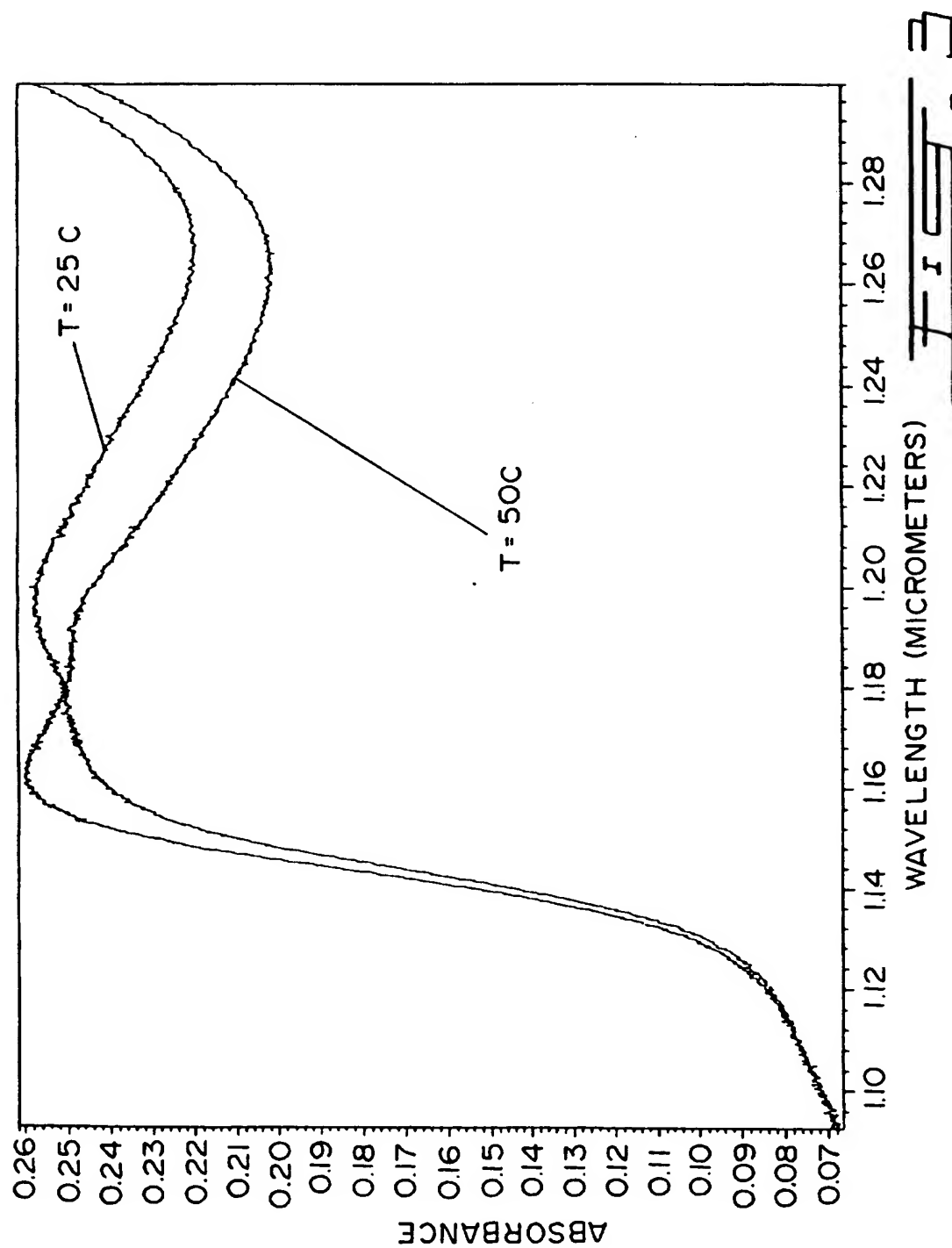10   separate the multiple wavelengths and a photodiode array detector adapted to issue the signals.

15.   An apparatus according to claim 11, wherein said detector comprises a diffraction grating to
15   disperse said multiple wavelengths and a photodiode array adapted to issue the signals responsive to the dispersed wavelengths.

16.   Use of the method of claim 4, in non-invasive
20   medical diagnosis.

FIG. 1

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$$\lambda \text{LOW} \longrightarrow \lambda \text{HIGH}$$

FIG. 2

FIG. 3

TEMPERATURE PREDICTION

FIG. 4

FIG. 5

PREDICTED VS. ACTUAL FOR: LUNG (DEGREES)

FIG. 6

FIG. 7

PREDICTED VS. ACTUAL FOR: TEMPERATURE (DEGREES)

FIG_8

TISSUE (FINGER) ABSORBANCE

$\underline{\mathit{Fig\_9}}$

SECOND DERIVATIVE

$X\ 10^{-5}$
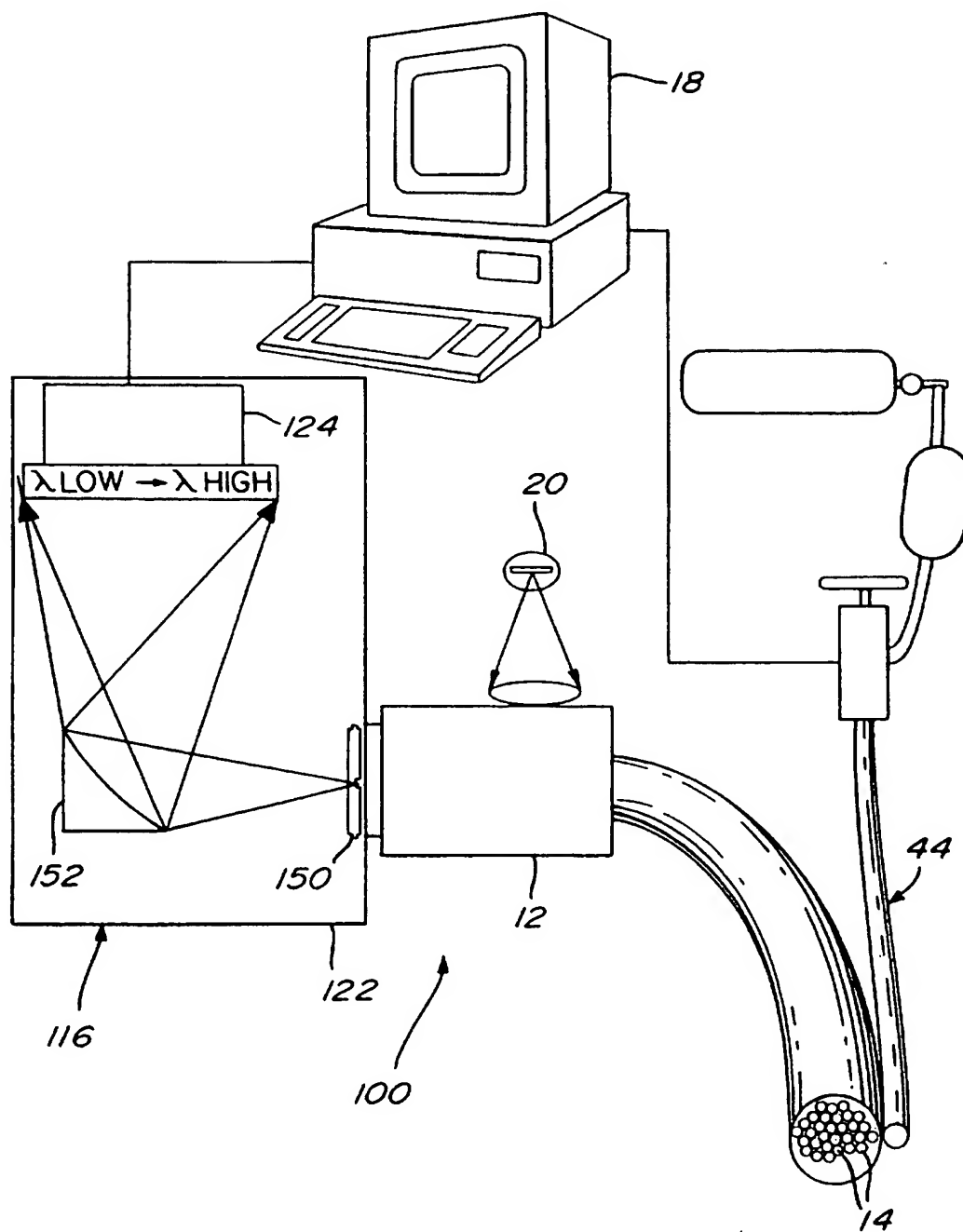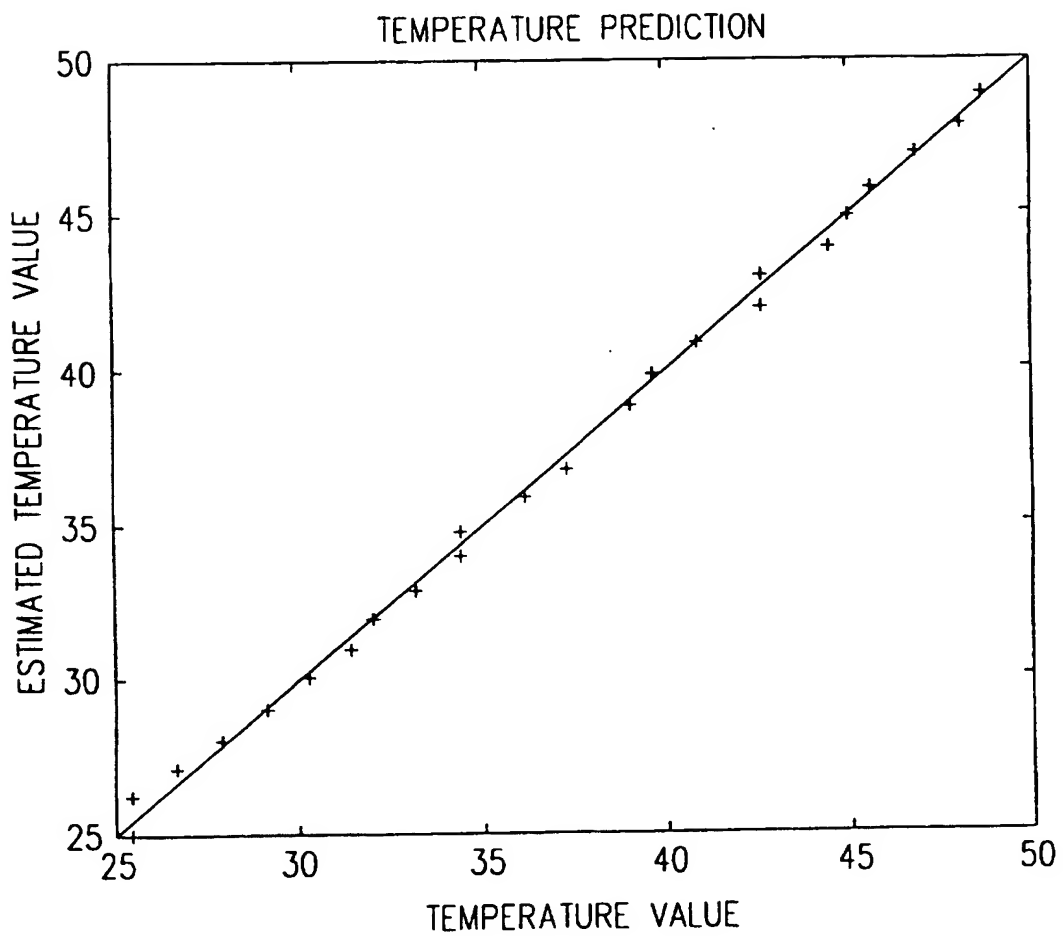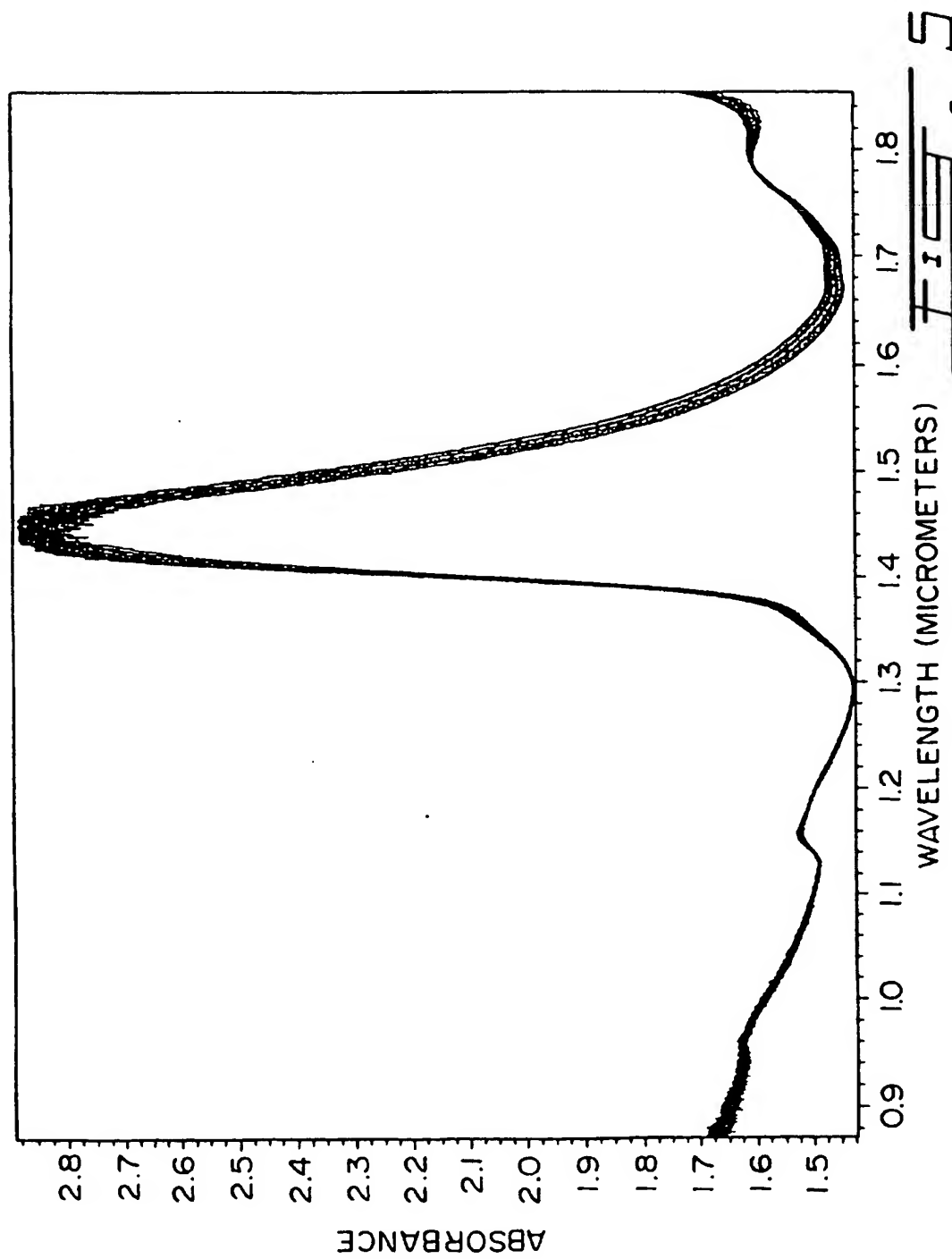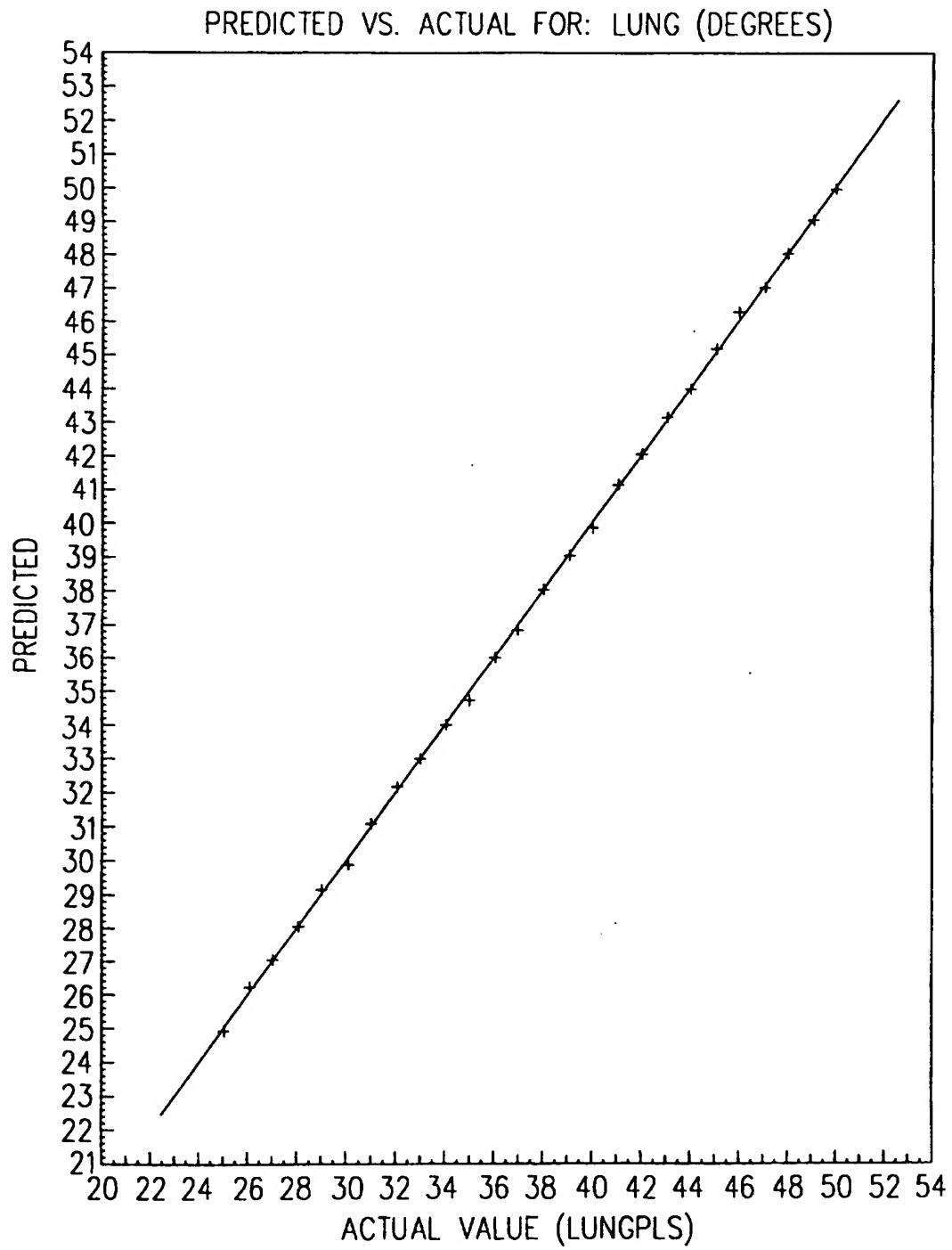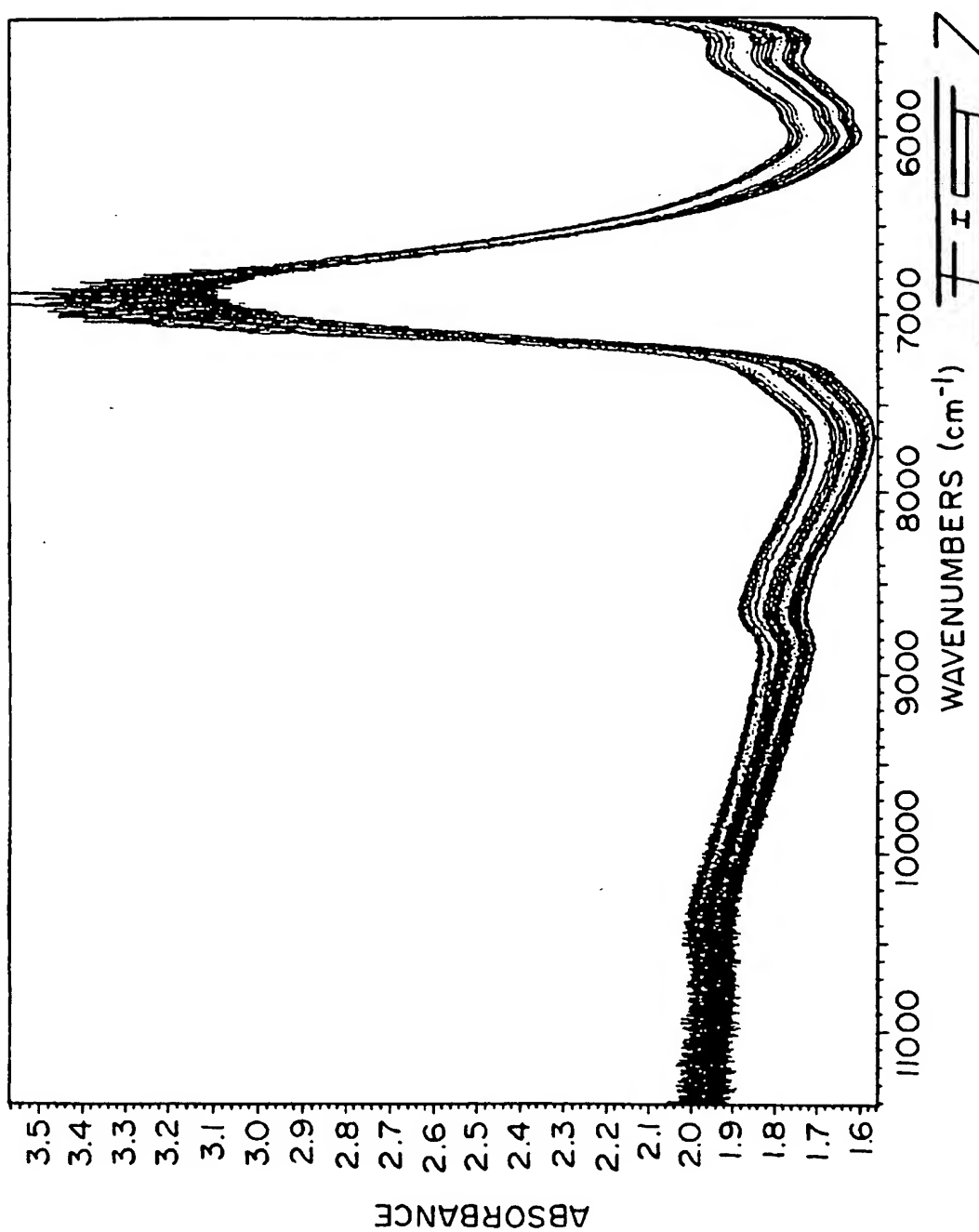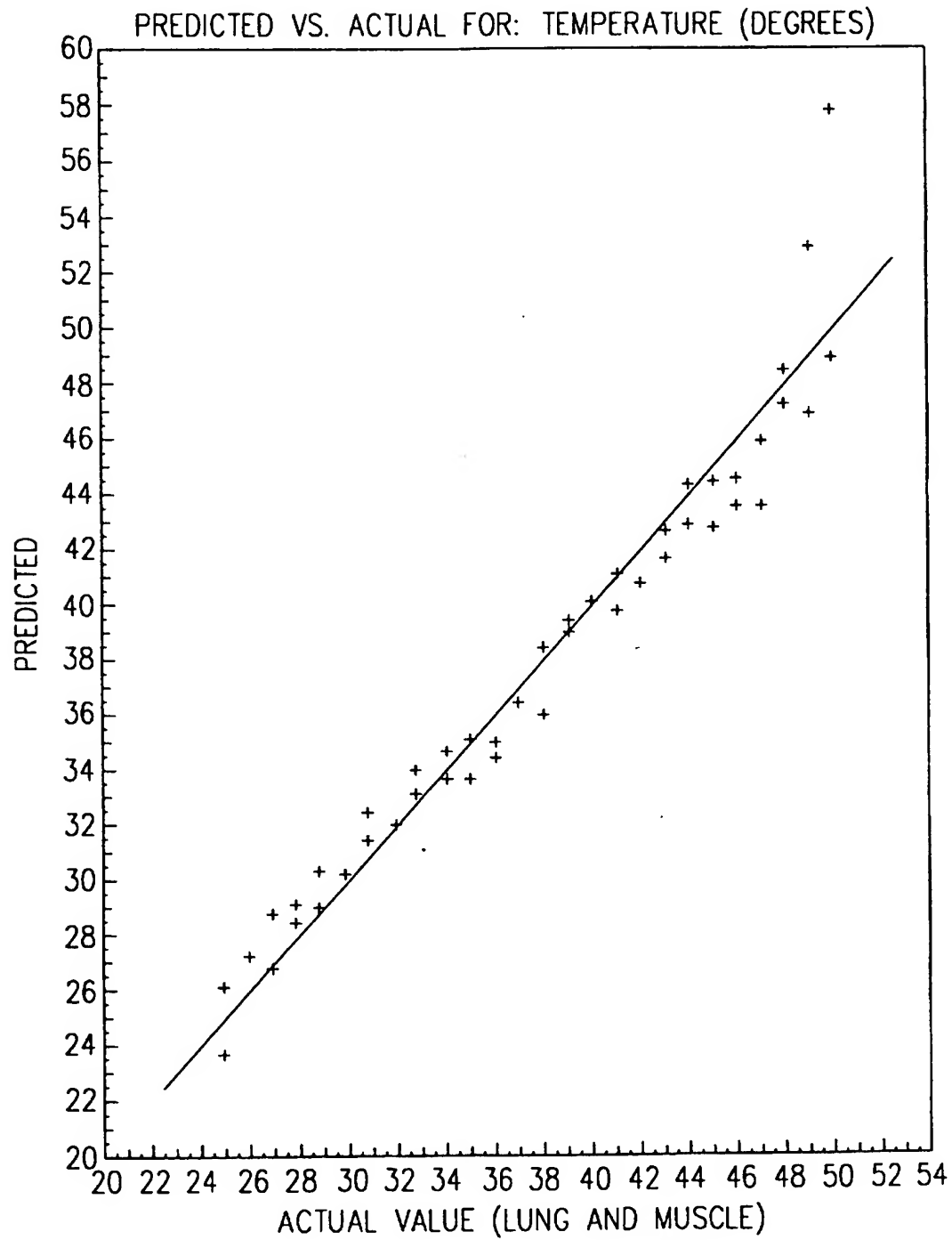
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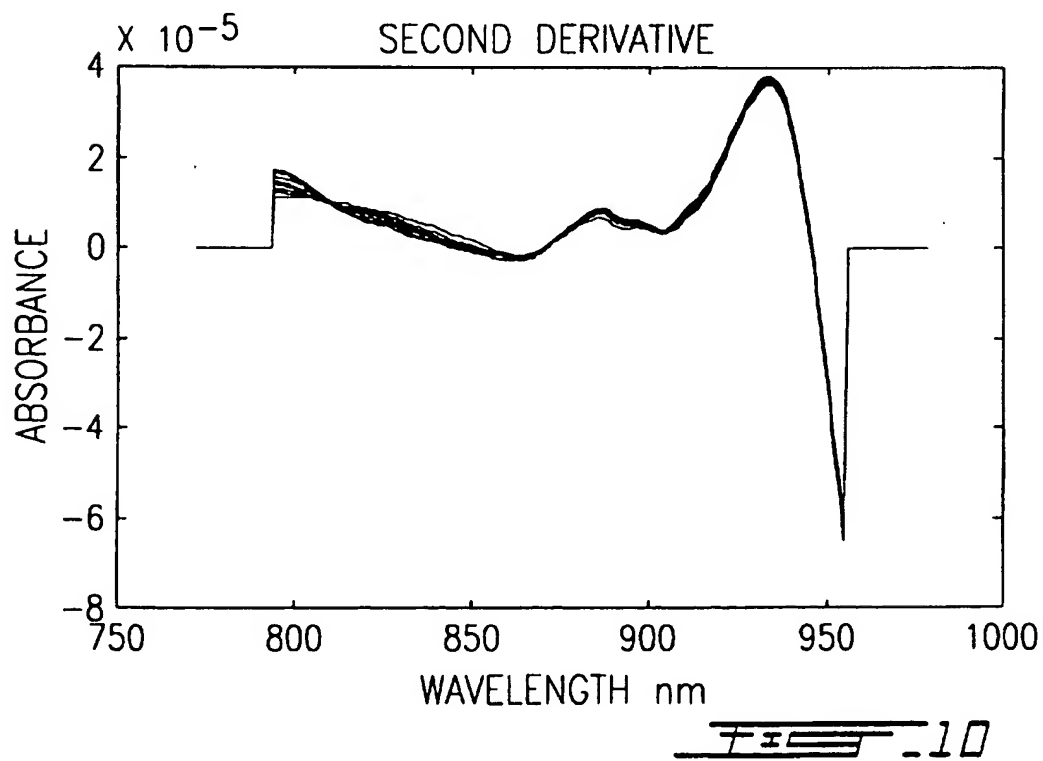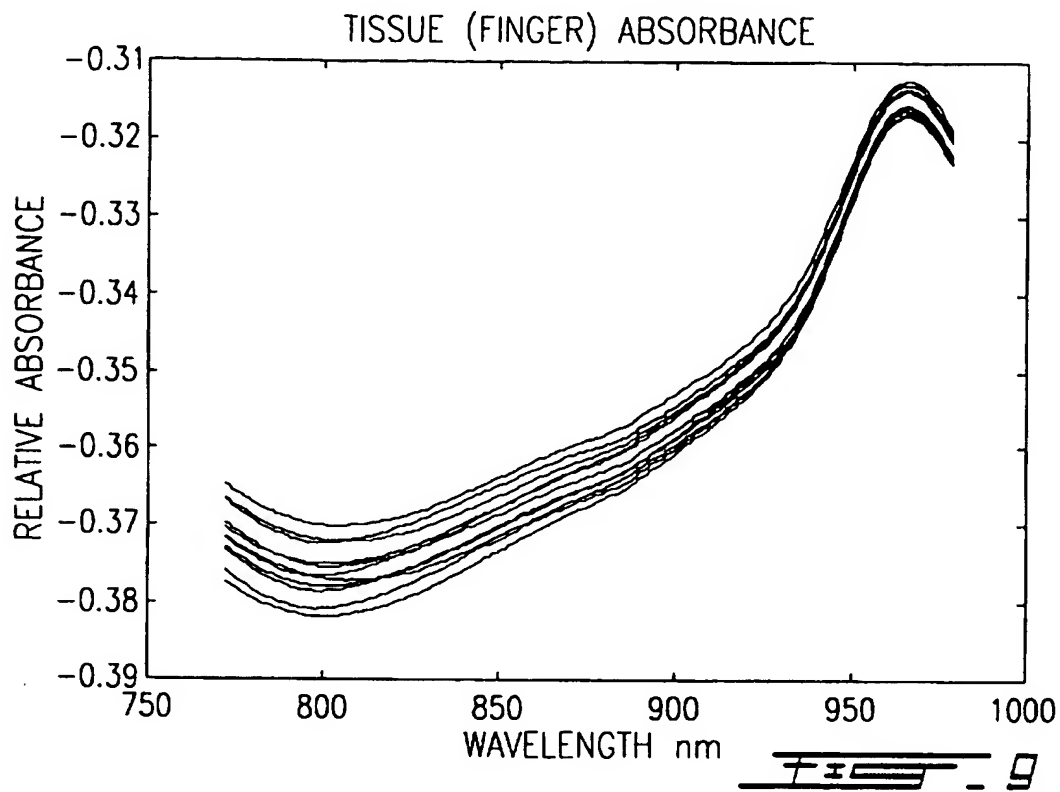
10/10
BEST ESTIMATION FOR CALIBRATION SET
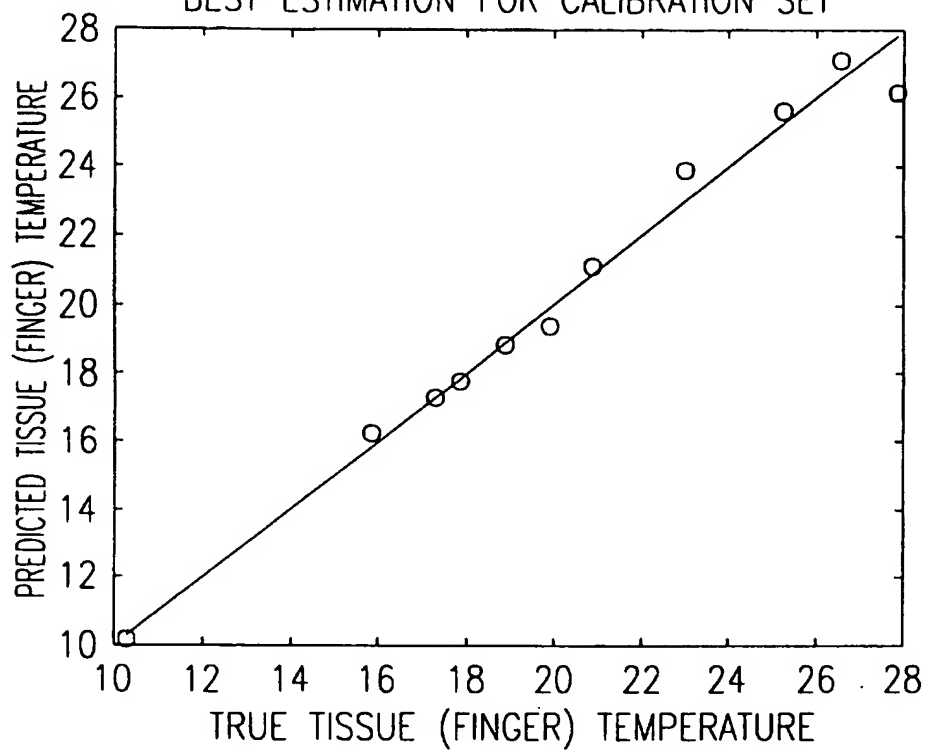
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BEST ESTIMATION FOR PREDICTION SET

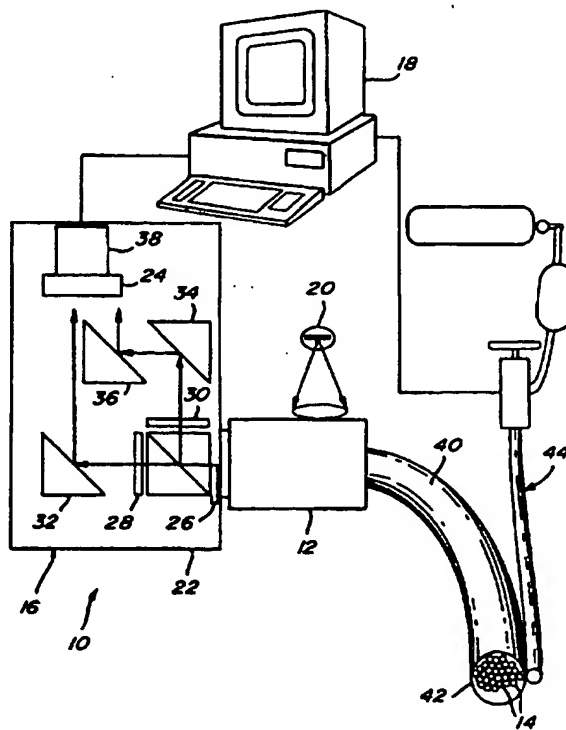

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PCT
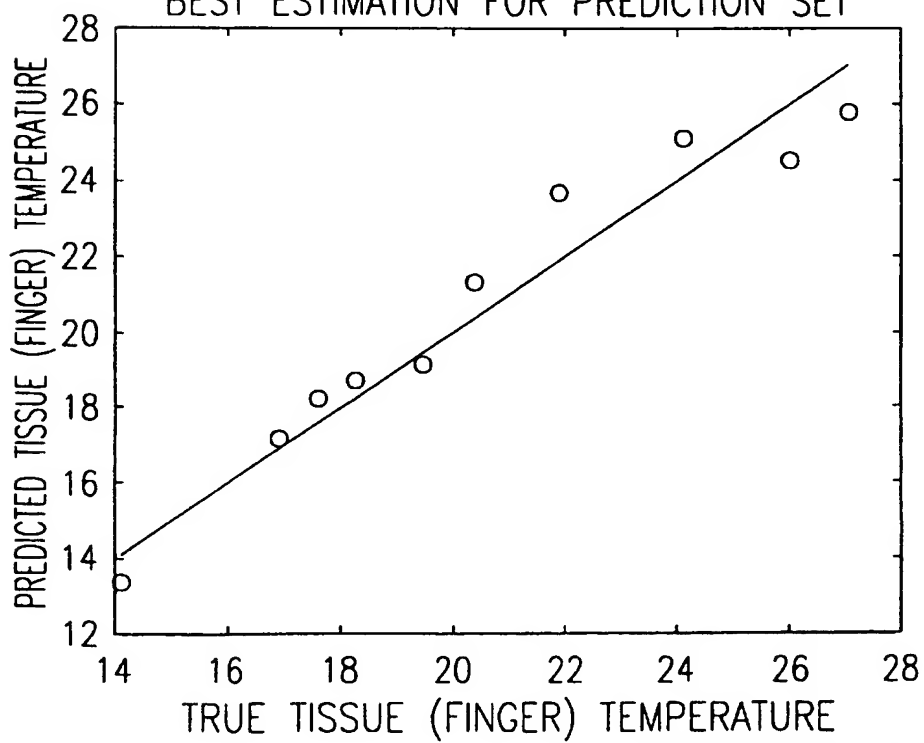
INTERNATIONAL APPLICATION PUBLISHED UNDER THE PATENT COOPERATION TREATY (PCT)

(51) International Patent Classification 6 : G01J 5/58	A3	(11) International Publication Number: WO 96/04535
		(43) International Publication Date: 15 February 1996 (15.02.96)

(54) Title: SUBSTRATE TEMPERATURE MEASUREMENT BY INFRARED SPECTROSCOPY

(57) Abstract

The temperature of an infrared radiation scattering medium which contains water, for example, biological tissue and paper, cement and clay substrates, is determined by exposing the medium to infrared radiation, measuring the reflected radiation scattered by the medium, comparing the reflected radiation with calibrated values, and evaluating the temperature of the medium from the comparison; the technique provides a means of non-invasive determination of temperature in biological tissue which has utility in medical diagnosis.

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INTERNATIONAL SEARCH REPORT

A. CLASSIFICATION OF SUBJECT MATTER
IPC 6 G01J5/58

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)

IPC 6 G01J G01N G01K A61B

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practical, search terms used)

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	US,A,5 262 644 (MAGUIRE) 16 November 1993 see column 1, line 15-19 see column 2, line 48 - column 3, line 9 see column 3, line 41-49 see column 3, line 60 - column 4, line 12 see column 4, line 28-33 see column 5, line 18-22 see column 6, line 5-38 see column 7, line 35-57 ---	1,10
A	EP,A,0 567 447 (LÜBBERS ET AL.) 27 October 1993 see page 1, line 1-6 see page 1, line 36-52 see page 4, line 3-12 ---	1,10

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| X | Further documents are listed in the continuation of box C. |

| X | Patent family members are listed in annex. |

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Date of the actual completion of the international search	Date of mailing of the international search report
28 February 1996	08.03.1996

Name and mailing address of the ISA	Authorized officer
European Patent Office, P.B. 5818 Patentlaan 2 NL - 2280 HV Rijswijk Tel. (+31-70) 340-2040, Tx. 31 651 epo nl, Fax (+31-70) 340-3016	Zinngrebe, U

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C.(Continuation) DOCUMENTS CONSIDERED TO BE RELEVANT		Relevant to claim No.
Category *	Citation of document, with indication, where appropriate, of the relevant passages	
A	US,A,4 245 507 (SAMULSKI) 20 January 1981 see abstract see column 4, line 10-34; figures 1,2 ---	1,10
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